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The Application of Bass Diffusion Model in Forecasting Telecommunication Services Users in Military Assistance to Civilian Authorities

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ABSTRACT

This paper analyses the application of Bass's diffusion model in forecasting the number of telecommunication services users in the event of natural disasters. Citizens' behaviour has been modelled in the case of an emergency situation caused by an earthquake with high magnitude. We analysed the area of an administrative district in the south-west part of the Republic of Serbia which includes two cities and three municipalities. To control the consequences of natural disasters, a unit of the Army of Serbia with the required number of radio transceivers for establishing communication between the vulnerable population and rescuers with command staff at the observed territory has been dimensioned. Special emphasis is given to the provision of telecommunication support in the military assistance in a relief operation with civil authorities.

Keywords: Natural disasters, relief operation to civil authorities, Bass's diffusion model, forecasting

1. INTRODUCTION

This research covered Raška district as one of the 29 administrative districts of the territory of the Republic of Serbia. This region is characterised as a highly seismic area frequently exposed to earthquakes and other natural disasters. Raška district is located in the south-west part of the Republic of Serbia covering an area of 3918 square km. It includes two cities: Kraljevo (as the centre of the district) and Novi Pazar, and the three municipalities: Raška, Vrnjačka Banja, and Tutin. The total size of the population that represents potential users of telecommunication services (primarily fixed and mobile telephony) in the observed territory (according to population census from 2011) is 300274.

The last registered earthquake shook this area on November 3, 2010, with its epicentre in Kraljevo. Earthquake magnitude was 5.3 / 5.4 of the Richter's scale with estimated intensity of VI level. Based on the Republic of Serbia seismic hazard map in terms of macroseismic intensity EMS-98 scale, Raška administrative district is designated with VIII-IX level, which is the maximum predicted macroseismic intensity in the Republic of Serbia[1]. This level represents EMS intensity with heavy damage potential and perceived violent shaking.

To quantify the impact of natural disasters on the use of telecommunications infrastructure, the Bass diffusion model was applied. Considering the specific situation in which the Bass diffusion forecasting model is applied, it is necessary to adequately define the *p* (percentage of innovators) and *q* (percentage of imitators) parameters[2]. The paper highlights these key points using the mathematical model. It also presents the solution to the problem related to the support of a telecommunication system within an area affected by a particular disaster of catastrophic proportions, i.e., an earthquake. The model actually refers to a certain area of the Republic of Serbia that may be threatened by this type of accident. In this paper, Bass's diffusion model has been used for the first time in forecasting the number of telecommunication services users in the emergency situation.

The Law on Emergency Situations[3], defines the role of the Army in such situations, where the activity is primarily related to the protection and relief operation of affected human population, animals, and property. The engagement of the Army in relief operations and assistance to civilian authorities is the third mission declared in the doctrinal documents of the Republic of Serbia, the Law on Defence and the Law on the Army of the Republic of Serbia[4,5]. Army involvement in this situation is directly related to natural disasters and other types of disasters that threaten the population and property.

Assistance to civil authorities to mitigate the consequences caused by a natural disaster includes various actions. One of the actions is support to telecommunications system. The key issue is the restoration of the broken communication system within the affected regional location and the ability to re-establish the system with assistance and engagement of the Army units.

The proposed structure of the Serbian Army unit in the Third section has been dimensioned on the basis of the Instructions on the methodology for risk assessment and plans for protection and rescue in emergency situations[6]. To realise the role of these units in the rescue of endangered personnel and provide conditions for broken communication system restoration, it is necessary to calculate the required number of radio transceivers (by power and frequency range). The territory of Raška district was taken as an input parameter for this calculation.

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2. PROPOSED USAGE OF BASS'S DIFUSSION MODEL

2.1 Problem Definition

As previously said, this research observes part of the territory of the Republic of Serbia, an administrative district consisting of two cities and three municipalities with 300274 populations in total. The population seen as potential users of telecommunication services (including public switched phones and cellular phones, with dominant influence of cellular phones) in the observed territory is 200000.

In the previous diffusion model application of forecasting new telecommunication services and technologies[7], the parameter of p was given low value (mean p=0.03), while the parameter q was granted higher values (mean q=0.38). On the other hand, some authors differentiated innovation and imitation parameter values according to the degree of economic development of the country[8]. Thus, for example, the average value of the innovation parameter p for developing countries is 0.0003, while for developed countries this value is 0.001. The mean value of the imitation parameter q in developing countries is 0.56, while in developed countries[9,10] this value is lower, and it is 0.51.

Determining the values of the parameters p and q is a very complicated process and is based on the observation of certain phenomena, analysis of similar events in the previous periods, and taking into account the peculiarities of a specific situation. Among the parameters p and q, a precise mathematical arrangement cannot be established (for example – inverse state: higher value of the parameter p – lower value of the parameter q, or vice versa). Instead, it is useful to introduce the q/p ratio which determines the speed of reaching a certain number of users (the maximum or the critical number), and defining the "shape parameter". If the relation high p/ high q is observed, the time to achieve the desired goal is short, while the relation low p/high q causes an increase in time[11-13].

In the case of emergency caused by natural disasters, it is logical to expect a large number of users of telecommunication services immediately after the occurrence of an accident, which results in the need to increase the parameter of innovators p. For this reason, it is necessary to choose the value of the parameter p in the range from 0.5 to 0.9, while the defined constant value of the parameter q equals 0.5 for all cases considered in this paper. In this way, a high p/high q ratio is achieved. Such values of imitators and innovators parameters express the most realistic scenario of the use of telecommunication facilities in a given situation. The variable value of the parameter p defines different degrees of destruction caused by the destructive magnitudes of earthquakes. Increasing the value of the innovation parameter yields an increased explosiveness in growth of the number of users, which reflects the reality of the observed situation. The constant value of the input parameter q indicates the unchanging influence of imitation parameter. In the emergency situation caused by the earthquake, the number of telecommunication services users reached its maximum in the period immediately after the natural disaster and remained unchangeable in the later stage.

Mathematical formulation of Bass's diffusion model is given as

$$\frac{dN}{dt} = \left[m - N(t)\right] \cdot \left[p + \frac{q}{m} N(t)\right], t \geq 0 \tag{1}$$

where

$N(t)$ = estimated number of telecommunication services users in terms of time

m = the total number of potential users

p = the innovators parameter

q = the imitators parameter

If one defines that $F(t)=N(t)/m$, then Eqn (1) gets the following form:

$$\frac{f(t)}{1/F(t)} = p + qF(t, t \geq 0) \tag{2}$$

where $f(t)$ denotes the first derivative of $F(t)$.

The solution of the previously equation is given by:

$$F(t) = \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}} \tag{3}$$

Finally, the cumulative number of telecommunication services users can be obtained as

$$N(t) = m \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}} \tag{4}$$

2.2 Analysis of the Global Bass Diffusion Model

A case in which the whole territory is affected by a natural disaster was studied and the number of telecommunication services users over time for the selected parameter values was analysed: p_1=0.9, p_2=0.8, p_3=0.7, p_4=0.6 and p_5=0.5, for innovators parameters, and constant values q=0.5 for imitators parameter. Figure 1 shows the family of curves representing the cumulative number of telecommunication services users in the function of the innovators parameter p change and in the case of constant parameter q. These five different parameters were chosen in order to present the dependence of the number

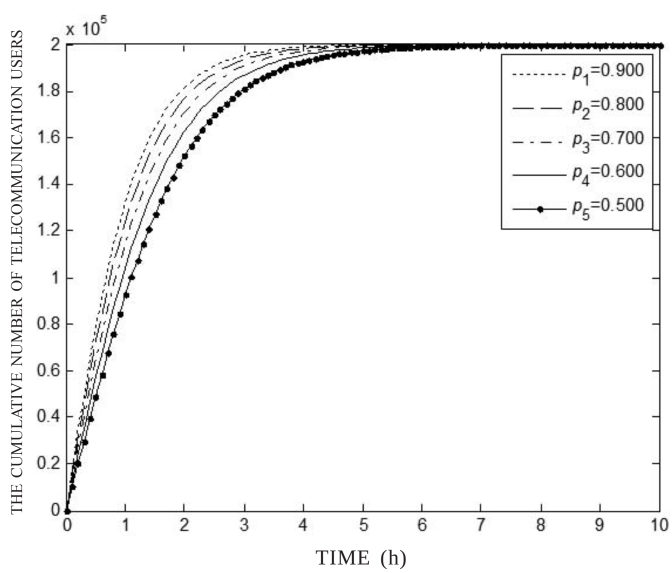

Figure 1. The cumulative number of telecommunication services users.

of telecommunication services users over time more precisely in the case of a different earthquake magnitude.

It was concluded that the obtained family of curves represent the cumulative number of telecommunication services users had the form of an exponential function, in contrast to the classical application of Bass's forecasting model, where the *S*-curve is achieved.

By analysing Fig. 1, it was concluded that in the initial stage, i.e., within the first hour after a natural disaster, the largest number of users of telecommunication services was recorded and it was more than 100000 users, which means that more than half of the population considered. Moreover, in the case with the lowest value of the innovation parameter p_5=0.5, the calculated value of the number of telecommunication services users was 92423. Precisely calculated number of users is shown in Table 1 for all values of the selected parameter *p*. It presents a calculated number of users within the first hour after a natural disaster, which represented 30 EBHC (equated busy hour call)[14].

Table 1. Calculated number of telecommunication services users within 1 hour

p parameter value	Number of users for *t*=1 h
p_1=0.9	132520
p_2=0.8	124320
p_3=0.7	115020
p_4=0.6	104450
p_5=0.5	92423

If the critical time analysis (during which the number of users of telecommunication services reaches its maximum) is carried out, the time that defines the speed of diffusion is obtained, i.e., time giving the maximum number of users in the shortest period of time. There are several methods to determine this time. Initial solution is obtained by Bass diffusion model, where the critical time is given by finding the first derivative of the diffusion function and equating to zero, which is defined as

$$t = \frac{\ln \frac{p}{q}}{p+q} \tag{5}$$

Analysing Eqn (5) , it was concluded that in the case when the parameters *p* and *q* are equal, the critical time becomes zero and then it cannot be explicitly determined. For this reason, in the monitored case, the critical time can be determined using Eqn (6) which is obtained by finding the second derivative of Bass 's functions and equating to zero[15] as,

$$t = \frac{\ln \frac{\left(2+\sqrt{3}\right)p}{q}}{p+q} \tag{6}$$

For given parameters *p* and *q* and defined population size, time for achieving the critical mass of telecommunication services users can be determined, as shown in Table 2.

Table 2. Calculated time for achieving the critical mass of telecommunication services users

m=200000, *q*=0.5	Critical time (*h*)
p_1=0.9	1.3601
p_2=0.8	1.3742
p_3=0.7	1.3774
p_4=0.6	1.3625
p_5=0.5	1.3164

2.3 Analysis of the Bass Diffusion Model Based on Territory Division

On the other side, in a situation affected by natural disasters, a different approach can be used. The model based on division of the territory can be applied in a particular number of areas (*i*) in accordance with the intensity of the natural disaster's negative effects. Each of the studied areas is characterized by different values of the innovators parameter p_i and the unique value of the imitators parameter *q*. The overall number of potential telecommunication services users in each territory is also known and is equal to m_i.

The analysis was conducted for five areas in all (*i*=5), while in each area, the number of potential users was m_1=30000, m_2=40000, m_3=50000, m_4=50000 and m_5=30000, which gives a total population of 200000 users in the observed region. For the parameter p_i, values in the range from 0.5 to 0.9 (p_1=0.9, p_2=0.8, p_3=0.7, p_4=0.6 and p_5=0.5) were assigned, respectively, while the parameter *q*=0.5 is constant for all areas. The value of the parameter p_i was assigned to areas in accordance with the intensity of the negative consequences caused by the natural disaster, where a higher value of the parameter p_i corresponds to greater intensity effects on material resources and manpower.

In this model, it is necessary to define appropriate initial moments of observing the cumulative number of users τ_i in each area. Since the natural disaster affects the particular area to a greater or lesser degree (which is directly defined by the choice of the parameter p_i), it is optimal to use equal and specific time τ_i=0 in all areas because of the simultaneous effects of the examined phenomena.

Based on the defined initial conditions, Fig. 2 shows the curves representing the potential number of telecommunication services users for each particular area.

If we consider the number of potential users in certain areas, as a result, the cumulative number of telecommunication services users in the analysed region can be obtained, according to Eqn (7):

$$N(t) = \sum_{i=1}^{n} \left(m_i \frac{1-e^{-(p_i+q_i)(t-\tau_i)}}{1+\frac{q_i}{p_i}e^{-(p_i+q_i)(t-\tau_i)}} \right) \tag{7}$$

where

$N(t)$ = the overall estimated number of telecommunication services users over time scale in the observed region
m_i = the number of potential users of the area (*i*)
p_i = the innovators parameter in the area (*i*)
q_i = the imitators parameter in the area (*i*)

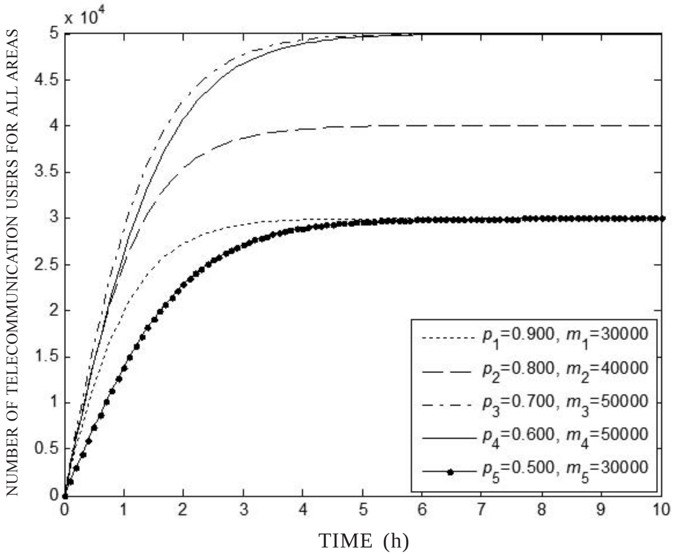

Figure 2. The forecasting of telecommunication services users for each particular area.

τ_i = the initial moment of using service in the particular area.

The existing models for forecasting telecommunication services with phased introduction is based on the territory division into areas with different physical limitations (easier or more complex possibilities for infrastructural works) or some other reasons such as financial, and all this is conditioned by technical and exploitation characteristics of the network.

In the defined model, considering the situation caused by a natural disaster, territory division into areas is meaningful, bearing in mind the fact that different influences and different effects of a natural disaster in analysed areas are possible. The cumulative number of telecommunication services users for the region composed of five areas is shown in Fig. 3.

Precisely calculated number of users in the region composed of five areas is shown in Table 3. It is the calculated number of users within the first hour after a natural disaster for all values of the selected parameter p_i and for given number of potential users m_i. The imitators parameter q_i remain with constant value for all areas (q_i=0.5).

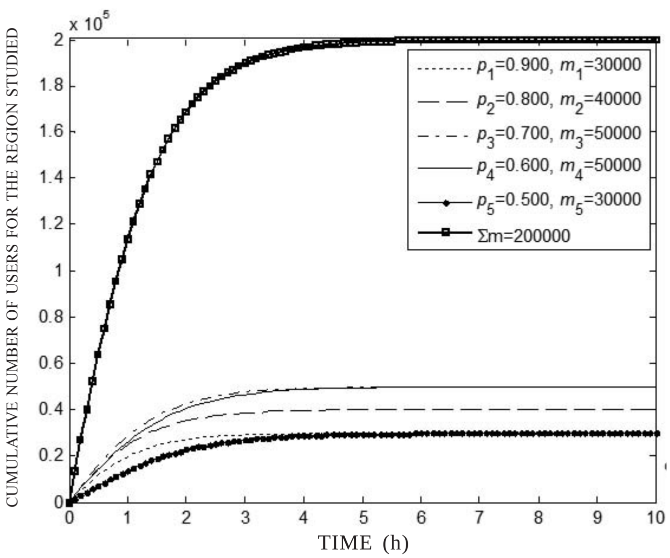

Figure 3. The cumulative number of telecommunication services users for the observed region composed of five areas.

Table 3. Calculated number of telecommunication services users within t=1 h for the observed region composed of five areas

p_i parameter values	m_i number of potential users	Number of users for t=1 (h)
p_1=0.9	m_1=30000	19879
p_2=0.8	m_2=40000	24684
p_3=0.7	m_3=50000	28754
p_4=0.6	m_4=50000	26113
p_5=0.5	m_5=30000	13864

3. ANALYSIS OF TELECOMMUNICATION FACILITIES FOR MEMBERS OF THE ARMED FORCES

A brigade-sized unit was engaged for the relief operation of the population and property in the studied territory, as shown in Fig. 4. One of the main tasks of the Serbian Army's Rescue Forces is to create conditions for the re-establishment of disrupted telecommunications infrastructure and facilitating communication. The military unit has been dimensioned according to the affected territory (Raška Administrative District which comprises two cities and three municipalities).

In the assistance to civil authorities of a particular territory in controlling the consequences of a natural disaster, military units have to be equipped with modern telecommunication facilities. In that way, the important role of the Army could be realised. For the telecommunication support, radio-transceivers in the VHF frequency range for communications over shorter distances, and HF frequency range for communication over longer distances, will have to be used. This is quite acceptable and obligatory solution since radio communications do not require additional telecommunication infrastructure in the territory previously destroyed by earthquake.

The assistance operation to civil authorities requires a brigade unit with the command-staff. Command-staff (Crisis staff) would be in direct communication with the battalion (three in total), while each battalion would consist of four companies. Each company consists of four platoons in which there are four squads.

On the other hand, direct communication is established between the armed forces and the civilian authorities. There are five radio links in total. Two radio links between the Command-staff and City crisis staff in Kraljevo and Novi Pazar, and three radio links with Municipality crisis staff in Vrnjačka Banja, Raška, and Tutin.

The calculation of the required number of radio-transceivers begins at the squad level (level 1). Each squad leader is equipped with a radio-transceiver in the VHF range of low power (2 W) for direct communication with the platoon commander (level 2). The platoon commander maintains communication with the squad commander (VHF low power at 2 W) and connection to the company commander (level 3)

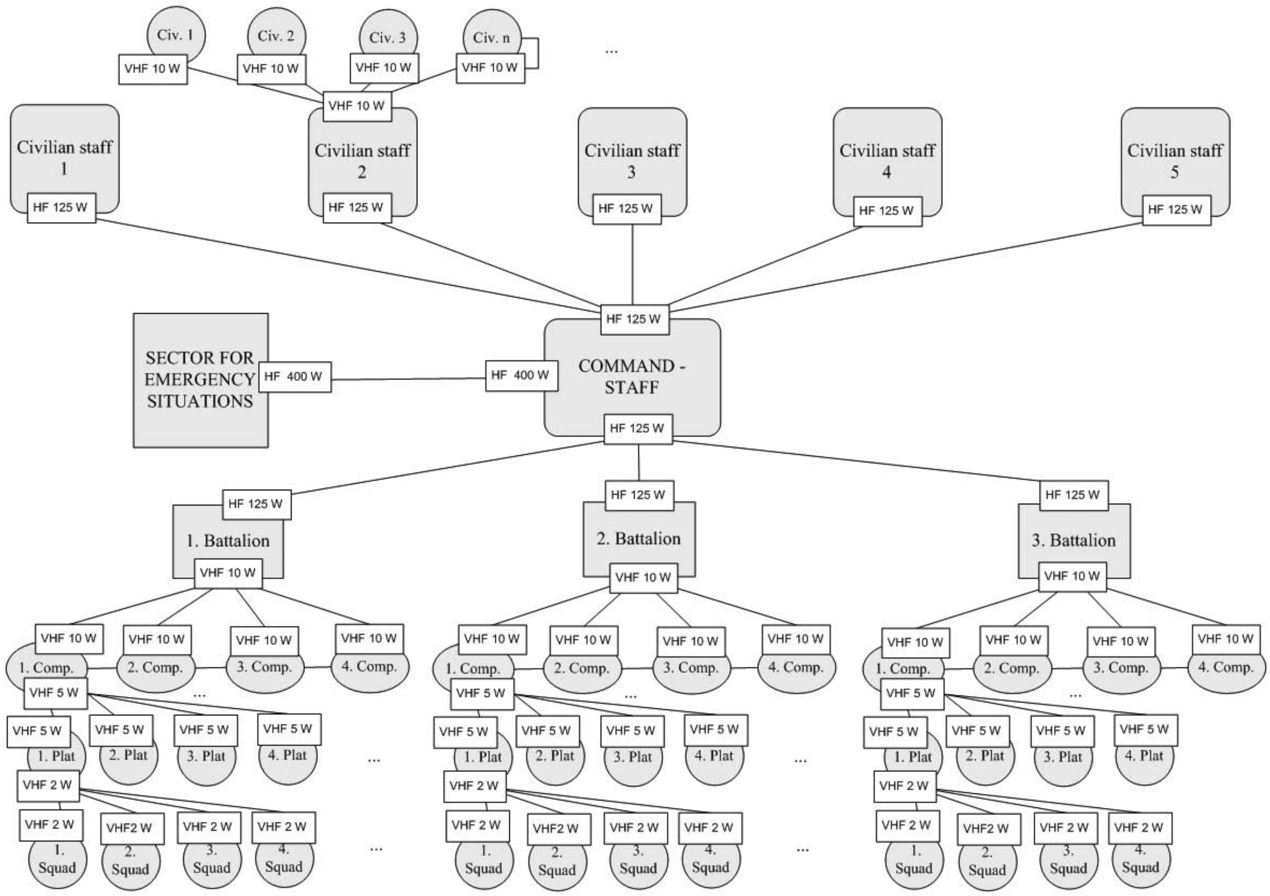

Figure 4. Organisation structure and communication links with the required number of telecommunication equipment (radios).

with radio-transceiver (VHF range with 5 W). Radio communication in the VHF band with 10 W power is maintained between the company commander and battalion commander (level 4). Battalion commander communicates with the brigade commander (Crisis staff) by the HF radio-transceiver at 125 W (level 5). The brigade commander has a communication link with the Department for emergency situations using HF radio-transceiver at 400 W (level 6).

On the other hand, the communication between the armed forces and the civil authority representatives (five civilian staff teams) is maintained over the HF radio-transceivers at 125 W (level 5). Connection between the civilian staff and a certain number of civilians is obtained by VHF radio-transceivers at 10 W (level 4).

According to the proposed organisation and composition of units for assistance operation to civil authorities in cases of natural disasters, it is necessary to engage a certain number of radios within a defined frequency range and power, as shown in Table 4, to maintain communication within the army units and civilian authorities.

Table 4. Required telecommunication equipment (radio-transceivers)

Frequency range and radio-transceivers power	Required number of radio-transceivers
VHF – 2 W	768
VHF – 5 W	60
WHF – 10 W	40
HF – 125 W	9
HF – 400 W	2

4. CONCLUSIONS

This paper presents the application of diffusion model in forecasting the number of telecommunication services users in the event of natural disasters as well as telecommunications support to military assistance operations to the civilian authorities. Emphasis is given for the situation of such proportions that the existing telecommunications infrastructure cannot be used because of the natural disaster effects. The army was engaged in providing telecommunications support in the population rescuing as the assistance to the civil authorities.

In an emergency situation caused by the earthquake, when all available telecommunication resources of the observed territory are destroyed, the only possible communication might be achieved via radio link. For this reason, the engaged units of the Army must be equipped with the necessary telecommunication devices of a specific frequency, range, and power.

It is concluded that the basic Bass’s diffusion model can be applied in forecasting the telecommunication services users in the observed emergency situations, and that it obtains the solution to such a complicated problem. The model is simulated in the MATLAB programme and the presented results give answers for a real situation, which happened in the south-west district region of the Republic of Serbia in 2010, with epicentre in the city of Kraljevo.

In this model, specific values were assigned to the defined variables that are realistic and applicable under the circumstances. These values directly correlate to the process of using the Army of Republic of Serbia for providing telecommunication support in the given situation. In this case, the appropriate needs of certain types of telecommunication devices (radio-transceivers) for a successful execution of the mission in which the Army is engaged are shown. The paper strictly determines the required number of radio devices for communication between the rescuers and the rescued, as well as the relationship between the Army unit and Command Staff-Sector for Emergency Situations, and Command staff, and Civilian staffs in the cities and municipalities.

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